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* Submitted to the Journal of Geophysical Research

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ABSTRACT

A balloon observation at 3.5 gm/cm^2 over Minneapolis on June 10, 1962 has resulted in upper limits from the quiet sun of less than 0.05 counts/cm^2-sec over the range 160 to 800 kev. This limit is considerably below those previously available. The detector consisted of a 3.4 cm dia by 5.4 cm NaI crystal surrounded, except for a one steradian forward aperture, by a 14.6 cm dia and 19.0 cm long CsI collimating shield connected in active anti-coincidence. The detector was servo-controlled to observe the sun, 180^o in azimuth from the sun, as well as vertical, horizontal and downward. The differences between the rates pointing to and away from the sun give upper limits for the solar flux at a 95% confidence level of 0.058, 0.048, 0.050, and 0.043 counts/cm^2-sec-Mev over the 163-325, 325-488, 488-651, and 651-774 kev range respectively. Since the Crab Nebula was in the detector aperture during the flight these upper limits also apply to that object.

Correction for the counter efficiency will give upper limits for the true flux somewhat higher than the above numbers, depending on the shape of the photon spectrum. Observation of the diffuse background γ-ray spectrum over this range due to cosmic-ray interactions in the atmosphere gave a result of 0.72 counts/cm^2-sec-ster-Mev around 300 kev, in general agreement with previous results (Peterson, 1963). The atmospheric line at 0.5 Mev due to positron annihilation was resolved. A γ-ray line at 660 kev was also detected and was determined to be due to Cs^{137} from fallout debris. The implied activity is $8 \pm 2 \times 10^{-3}$ disintegrations per gm-sec, averaged from 70,000 to 128,000 feet. Additional information pertinent to the application of this detector system to γ-ray astronomy was obtained.

INTRODUCTION

The existence of a γ-ray flux from the quiet sun has been the subject of a number of theoretical and experimental works which have been reviewed by Dolan and Fazio (1965). Such a flux must of course be the result of non-thermal electromagnetic and nuclear process in the solar corona, chromosphere, or the upper layers of the photosphere, and its detection would therefore be of considerable astrophysical significance. The observations of X-ray and γ-ray bursts during solar flares have resulted in additional interest in the quiet time problem. In this paper we wish to report the upper limits resulting from a search for solar photons in the 100-kev to 2-Mev range from a balloon-borne instrument.

Detecting the weak γ-ray fluxes expected poses a considerable experimental problem. Even at extreme balloon altitudes, where the solar γ-rays above about 50 kev would be little attenuated by the residual atmosphere, the γ-rays produced by cosmic-ray secondaries result in considerable background from outside the solar direction (Peterson, 1963). Therefore, a detection system with an efficient collimator, an inherently low background, and an independent means of measuring this background is required. The experimental techniques employed in this measurement were designed to meet the above criteria.

DETECTOR AND INSTRUMENTATION

The detector consists of a NaI(Tl) scintillator counter surrounded, except for a small forward aperture, by a CsI(Tl) collimating shield connected in electrical anti-coincidence. A sketch of the detector is included in Figure 1. The shield is of sufficient thickness to attenuate

γ-rays from wide angles. Passive collimators made of high Z materials, such as lead, produce more γ-rays than they remove because of cosmic-ray interactions within the absorbing material. A comparison of the total counting rate of the central crystal in the shield without anti-coincidence with that obtained in the atmosphere on previous measurements clearly demonstrates this fact. This detail will be discussed in a later section. The details of the detector and some of its properties have been described previously (Frost and Rothe, 1962). A curve showing the directional response of the detector to Cs^{137} γ-rays is shown in Figure 2. The response, and therefore the collimation efficiency, is of course energy dependent through the absorption cross-section for CsI.

The central counter has a forward area of 9.1 cm^2, a geometry factor for an isotropic flux of 19.2 cm^2, and photopeak conversion efficiencies of 23, 18 and 13 percent for 511, 662 and 1280 kev respectively. The isotropic geometry factor of the shield crystal is 360 cm^2, and the effective telescope factor at 660 kev is about 10 cm^2 steradian. Although reasonable estimates can be made, the detailed dependence of the telescope factor on photon energy is, at this time, unknown.

The block diagram of the balloon instrumentation is also indicated in Figure 1. Two nearly independent pulse-height analysis schemes were employed. A gated pulse stretcher which modulated a wide band subcarrier was used to cover the range 140 to 800 kev. Over the range 300 kev to 2.2 Mev, a digital technique, in which a coded word was transmitted for each event, was employed. In addition, overall counting rates were monitored via scaler-adder techniques on independent subcarriers. Because of anticipated effects due to large cosmic-ray events in the shield, two anti-coincidence pulse lengths were generated. Events greater than about 130 kev equivalent produced a 10 μ-sec pulse while events of about 3.5 Mev or larger generated a long 200 μ-sec gate. The total deadtime due to the shield was independently monitored.

The entire 20-kilogram detector was mounted in a gimballed framework which could be servo-controlled with respect to the sun in elevation and azimuth, or locked to preprogrammed elevation positions. The sun was sensed with a series of acquisition and fine eyes. Pointing and alignment accuracies were on the order of a degree, much less than the nominal 30° half angle of the detector response. An independent target eye was provided to verify solar acquisition.

The detector was mounted about one to two feet from condensed masses, such as batteries, electronics, and servo components. Under no normal pointing or positioning sequence was there any material, other than a few inches of Styrofoam, within the forward aperture of the detector. The PM tube of the central detector, of course, does lie within this solid angle, and contributes about 6 gm/cm^2 of aluminum, glass and potting materials.

BALLOON FLIGHT

The instrument was launched at 0514 CST on 10 June 1962, reached ceiling altitude of 128,000 feet at 0740 CST, and floated nearly level for 8 hours. Detector position was vertical until 110,000 feet when a timer initiated the positioning sequences. In this sequence the detector was pointed downward, vertical and horizontal, for five minutes each to obtain background information. After acquiring the sun for 25 minutes, the detector was swung 180° from the sun, with the elevation fixed to the same angle as the previous acquisition, for 20 minutes. Since atmospheric background γ-rays at extreme altitudes may depend on zenith angle, but unlikely on azimuth, this provided an experimental determination of the background to be subtracted. Eight such sequences occurred during the flight as indicated in the flight profile, Figure 3. The programming of the flight proceeded as planned, and although the servo oscillated with a small amplitude at the torsion frequency of the suspension, the target eye indicated the pointing errors were always less than about 3°. The small settling of the balloon, from 3.1 to 3.8 gm/cm^2, produced a very small effect which could be neglected.

The overall rates of the central counter, in anti-coincidence with the shield, are also shown in Figure 3. These rates have been corrected for the deadtime, shown as a function of atmosphere depth in Figure 4. There is no obvious difference in these rates when pointing toward and away from the sun, indicating that the background and atmospheric contributions to the spectrum dominate the solar flux. Integral rates obtained from the two data transmission systems differed by a large factor although presumably the results should be independent of the electronic system being used. The rates as a function of atmospheric depth also presented a most puzzling set of data, shown in Figure 5. Although the rate of large events in the shield agreed with that predicted from the cosmic-ray flux, the number of small events was many factors larger than anticipated.

Return of the instrument in excellent condition to the laboratory allowed an extensive post-mortem to be conducted. Inspection immediately revealed that the long anti-coincidence shield pulse was inadvertently left disconnected from the high range pulse-height analyzer during the flight. This unfortunate circumstance apparently resulted in the high rates from this analyzer, thus precluding the use of the data from this channel to obtain low background measurements of the solar spectrum at the higher energies. Some anti-coincidence inefficiency was expected due to large cosmic-ray events in the shield; its magnitude was completely unanticipated. A series of further laboratory studies have since provided considerable added understanding of the properties of these large active anti-coincidence shields, and have allowed interpretation of the results of this flight.

INTERPRETATION OF THE COUNTING RATES

Sea Level Studies

Although the cosmic-ray composition at sea level is markedly different than at high altitudes, the effects of large energy losses in the shield could be investigated by using sea-level mesons. A minimum ionizing particle passing directly through the shield crystal and undergoing energy loss only through ionization and collision will lose about 100 Mev. The average sea-level meson was found to leave a total of about 0.04 microcoulombs of charge on the anodes of the photomultipliers observing this crystal. The current pulse associated with each event consisted of a very large number of small events, up to 100 kev equivalent, superimposed on the generally exponential tail of the event. These small pulses, which continued for about 100 microseconds after the initiating event, are possibly due to the excitation of long-lived phosphorescent states in the crystal. The large charge pulse completely saturated the shield crystal phototube divider networks, and the input amplifiers, and rendered further anti-coincidence action impossible for at least 100 microseconds after a cosmic-ray event.

Effects in the Shield

Although this effect did not cause serious anti-coincidence inefficiencies at sea level, the results at high altitude can be inferred. Here the event rate due to cosmic rays is some 100 times greater, the particles are mostly protons and heavies which interact, and one may easily imagine stars in which hundreds of Mev are instantly lost within the CsI shield. These large events will produce many small pulses over several hundred microseconds, which will hardly have decayed away before the next large event occurs, about a millisecond later. The result is that the crystal is sort of glowing nearly continuously, and producing small events at a rate more proportional to the total ionization loss rather than the individual particle numbers in the crystal. This conclusion is strikingly verified in Figure 5. Here the number of large events in the shield (>3.5 Mev) has an atmospheric transition curve which resembles that of a single Geiger counter, while the total number of events greater than 50 kev has a depth dependence resembling that of an ionization chamber. (Masley, et al, 1962).

At 3.5 gm/cm^2 the shield rate for large events was about 750 counts/sec. independent of detector position within about 5 per cent. Using a geometry factor for an isotropic flux of 360 cm^2, the flux is 2.1 cm^{-2}-sec^{-1}, which is in close agreement with the accepted values of primary and secondary cosmic-ray particles, as measured with a Geiger counter, at this latitude, time, and depth (Masley, et al, 1962). At this location the integral γ-ray spectrum above 3.5 Mev is apparently less than about 0.1 photons/cm^2-sec since the rate can be accounted for within statistics by charged particles. The shield rate for low energy events was about 15,000 counts/sec or 20 photons of 6 kev equivalent or greater per incident cosmic ray. Only about 4000 counts/sec would be expected from atmospheric γ-rays external to shield.

Rates of the Central Counter

The integral rate of the central counter above 300 kev with no anti-coincidence was 128 counts/sec. Of this, about 40 counts/sec would be due to charged cosmic-rays and 88 counts/sec due to γ-rays. The expected integral rate for the bare crystal in air due to γ-rays at this depth was about 20 counts/sec. Since the shield is at least several photon mean free paths thick over most of the energy range considered, the atmospheric γ-radiation which contributes to the bare crystal rate must be strongly attenuated when it impinges on the detector from directions outside the entrance cone. The γ-ray count rate just quoted of the central crystal with no anti-coincidence is nearly a factor of 5 higher than the expected bare crystal rate and about 20 times larger than the rate obtained with complete anti-coincidence. Therefore it seems reasonable to conclude that most of the 88 counts/sec measured are generated in γ-ray producing interactions of the charged particles with the high Z shield matter.

The large rates of the high range pulse-height channel may now be interpreted as due to γ-ray production in the shield by cosmic rays during the interval after a large event in which the anti-coincidence channel was ineffective. Since the probability that an event occurs within the shield deadtime is proportional both to the deadtime and to the rate, the number of false events varies as the square of the rate. This accounts for the observed absorption length of the counts in the high range analyzer for these events, shown in Figure 5, below the transition maximum. This length is 90 gm/cm^2 or half the accepted value of about 180 gm/cm^2 (Peterson, 1963). The absorption lengths of the remaining rates measured in this experiment were in general agreement with accepted values, although some anomalous effect apparently occurred deep in the atmosphere.

At sea level the integral rates of the analyzers were in agreement, and were presumably counting local radioactivity. As seen in Figure 5, the rates dropped only a factor of two after launch, and were rather independent of depth for several hundred gm/cm^2. Usually, on an atmospheric γ-ray experiment at these energies, the rate is observed to drop a factor of 5 or 10 immediately after launch, and joins smoothly onto the extension of the 180 gm/cm^2 cosmic-ray absorption length. To test an assumption that the background of the detector was limited by its own radioactivity, the entire detector was placed in a 4-inch lead hut. Although the shield spectrum dropped a factor of 10 or so, the spectrum from the central counter was reduced only about one-half, either with or without the shield anti-coincidence. Therefore, at sea level production in the shield by mesons is apparently a small effect, compared to local radioactive background. Since no γ-ray lines were observed in this residual background spectrum, an offending radioactive isotope could not be identified, and the assumption of a residual radioactive background within the detector itself must be regarded as unverified. This background, whatever its origin, contributed about 20% to the integral rate at 3.5 gm/cm^2 of the central crystal with full anti-coincidence, and was therefore not entirely negligible.

In summary, at floating altitudes, the γ-ray spectrum in the central counter measured with the low range analyzer consists mostly of cosmic-ray produced atmospheric γ-rays either within the forward aperture, or which leak through the CsI shield. A small background is contributed by a residual effect. A neglectable portion of this spectrum is contributed by production in the CsI. Because of the loss of complete anti-coincidence, most of the high range spectrum is due to shield production. Significant data on the solar spectrum may be expected only from the low range analyzer data and in the range 140 to 800 kev.

UPPER LIMIT SOLAR γ-RAY SPECTRUM

The spectra obtained at 3.5 gm/cm^2 averaged over the entire flight are shown in Figure 6. Spectra for the low range analyzer are indicated for the various pointing positions where significant differences were obtained. Apparently at this depth there is a dependence on zenith angle. As indicated previously, the differences to and away from the sun were small. These data are therefore averaged together in Figure 6, and give a background spectrum at an average zenith angle of about 35°. The high range data are averaged over all positions. Corrections for channel width, and shield and telemetry deadtimes, have been applied. These spectra will be discussed later in this paper in terms of cosmic-ray production, detector properties, and other effects.

When subtracting spectra and using the difference to obtain upper limits on the solar flux it is tacitly assumed that other strong sources are not within the aperture, either when observing the sun, or in the 180° background position. Furthermore, it is assumed that the background is indeed independent of azimuth. The Crab Nebula, which is now known to emit strongly at energies to 60 kev (Clark, 1965) was only 3° from the sun and therefore well within the acceptance cone. On an interval by interval basis no significant differences were obtained looking to and away from the sun, as indicated in Table I. Averaging over the entire 800 kev range also gave no statistically significant differential rates, hence this experiment can provide only upper limits on the solar γ-ray spectrum. These limits of the counting rate, computed at a 95% confidence level are shown in Table I and Figure 7 and of course also apply to Crab Nebula. Figure 7, by way of comparison, also indicates the data of other experiments which gave results on the sun.

These upper limits are of the dimensionality counts/cm^2-sec, uncorrected for efficiency, and allow a direct comparison with the results of previous work. Correction for efficiency of a continuous spectrum as measured here requires spectral knowledge to the highest energies. In order to provide a stringent upper limit for γ-ray line emission in any range, corrections for the known photoefficiency may be applied. The results of this procedure are also indicated in Table I and Figure 7, at a 95% confidence level, and are appropriate under the assumption of no continuum, and no emission at higher energies. A realistic upper limit on the true photon flux is somewhere between these sets of data.

The integral rate, for events greater than 774 kev in energy did, however, give a positive excess of 0.25 ± 020 counts/sec. This would imply a positive integral solar γ-ray flux of >800 kev of 0.024 ± .002 photons/cm^{2}sec, uncorrected for counter efficiency and atmospheric absorption. Although this is consistent with previous upper limits considerable caution is in order because of the lack of spectral information. In fact, the difference in rate is most likely due to a small anisotropy in low energy cosmic rays at this altitude.

Measurements at somewhat lower energies were made by Frost (Lindsay, 1965) and Peterson (1965) on the OSO-I. Limits on cosmic γ-rays over this energy range obtained by Arnold and his collaborators (Metzger, 1964) on the Ranger series also apply to the sun. These observations have in fact provided the lowest results on the possible γ-ray lines at 0.5 and 2.2 Mev to date. These limits are 0.01 and 0.005 photons/cm^2-sec, respectively.

This experiment finds a difference of -0.003 ± 0.008 photons/cm^2-sec when subtracting the 0.5 Mev flux observed looking away from the sun from that flux observed when pointed at the sun. The data here yield an upper limit at a 95% confidence level of 0.013 photons/cm^2-sec for the non-flare solar 0.5 Mev flux.

The data at lower energies, in the 2 to 20 kev range, are from the recent observations of Chodil, et al (1965). Here continuum recombination radiation and thermal bremsstrahlung may be expected (Elwert, 1961). Shown is the spectrum calculated for a thin, hot gas at 4.5×10^6 °K, neglecting recombination and absorption effects. Other recent observations of solar X-rays have been published by the NRL group (Acton, 1963) by Van Allan (1965) from the Injun I, and by Culhane (1964). Many of these observations extend below one kev, where line emission may dominate. Since these observations generally did not provide detailed spectral measurements above 1 kev, the incident energy is a sensitive function of the assumed wavelength distribution. Both are apparently highly variable in time. It is not the intent here to provide a critique of these observations, but merely to indicate their flux relative to the higher energy photons discussed in this work. Limits on the quiet and active sun in the 100 Mev range have also been obtained by a number of workers. (Kraushaar, et al, 1965).

Data obtained here apply to the quiet sun. No outstanding flare or radio events for 10 June 1962, were reported (U. S. Dept. Commerce, Nat. Bur. Standards, 1962). During solar flares, fluxes in the ten to hundred kev range having intensities several orders greater than these limits have been observed.

UPPER LIMITS OF CRAB NEBULA GAMMA RAYS

As indicated previously, the Crab Nebula was within the detector aperture on the flight date of June 10, 1962. Since no significant fluxes were obtained above background when pointing in the solar direction, the upper limits on the counting rate obtained for the sun also apply to the Crab Nebula. These limits, along with the X-ray spectra reported by Clark (1965) are shown in Figure 8. The results obtained here are consistent with his work, and extend the limiting spectrum to nearly one Mev. Also shown are the measurements at lower energies obtained by the NRL group (Bowyer, et al, 1964). Other results in the γ-ray region for the Crab Nebula have been reported in a recent note by Gould (1965).

ATMOSPHERIC γ-RAY BACKGROUND AT 3.5 GMS/CM^2

In order to perform a γ-ray astronomy experiment from balloon altitudes the response of the detector to the intensity, spectrum and angular distribution of atmospheric γ-radiation must be understood. For a directional detector with a given field of view and negligible inherent background, the residual atmospheric γ-radiation above the detector obviously sets an unvoidable limit on the magnitude of extra-terrestrial fluxes that can be detected in a given period of observation.

As indicated previously, spectra from the low-range analyzer, shown in Figure 6, result mostly from atmospheric γ-rays produced by cosmic-ray interactions outside the detector. These photons originate from the degraded products of π^o meson decays, which build up to form a steep spectrum at low energies via multiple Compton scattering (Vette, 1962) (Peterson, 1963). The spectra, averaged over the entire flight, shows small but significant differences for the various pointing positions. Measurements of anisotropies in γ-rays at these depths have not been attempted previously. Peterson's observations (1963) at this location with a 4π geometry indicate some anisotropy, since a depth dependence of 6 percent/gm-cm^{-2}, decreasing toward zero depth was obtained.

Even under the assumption of uniform production per gram of air within a photon mean free path of the detector, a zenith angle dependence is expected at 3.5 gm/cm^2 because of the finite source thickness when the detector is pointed out of the atmosphere. This effect is of the correct magnitude for the differences in Figure 6. The spectrum at 90°, which is not shown, is identical to that looking down. The possible isotropic cosmic γ-ray fluxes indicated by the Ranger data (Metzger, 1964) can contribute only about 15 per cent to the vertical rates at 150 kev, and less at higher energies.

No changes were noted in the shape of the spectrum as a function of pointing position. The 0.5 Mev line, due to positiron annihilation, is clearly resolved, and has a value of 0.5 counts/sec. If the efficiencies of the anti-coincidence shield and the central counter were 100%, there were no absorption in the forward aperture, and no spurious background, dividing this rate by the approximate telescope factor of 10 cm^2-steradian would give the flux. The value obtained is about 0.05 photons/cm^2-sec-steradian, or within a factor of two of the $0.025 \pm .002$ measured previously by Peterson (1963). The first assumption begins to fail at energies above about 300 kev, the second at lower energies. As indicated previously, about 20% of the rate above 300 kev was due to an unknown background effect. However, this effect and shield leakage were apparently insufficient to mask the small anisotropies discussed above.

Figure 9 shows the differential photon spectrum (between 130 and 700 kev) uncorrected for efficiencies and absorption. Providing none of the above assumptions are seriously in error, this is a measure of the photons produced by cosmic ray interactions at 3.5 gm/cm^2 and $\lambda = 55^o$ magnetic. A previous measurement of the isotropic flux at this location, but at 6 gm/cm^2, has been made by Peterson (1963), with a 2" by $2\frac{1}{4}$" phoswich scintillation counter. The depth dependence allows a correction to 3.5 gm/cm^2, and since the fluxes are reasonably isotropic, the experiments may be directly compared since the counters have similar efficiencies. This comparison is also shown in Figure 9. These measurements compare well with Peterson's fluxes at low energies, but are above the previous observations at higher energies, most likely because of the finite shield thickness.

Another feature of the spectrum is the apparent line between 600 and 700 kev. This line, which was not observed by Peterson (1962), fits well both in position and resolution with sea-level calibrations using the 660 kev Cs^{137} γ-ray line. This conclusion was verified by doing a reduction at higher pulse-size resolution than indicated in Figure 6. This line was not present during sea-level background runs, as previously discussed, either before or after the flight, although a flux at the level observed would have been easily detected during these tests. Since this feature of the spectrum cannot be attributed to contamination of the detector, it must be a property of the atmosphere.

Among the fission products of atomic-bomb detonations is the isotope Cs^{137} (Gustafson, et al, 1962). The moratorium, which had been in effect was lifted by the USSR with a test series in September-October 1961.

Anderson (1965) has reported balloon observations of nuclear debris from these tests. The USA continued low yield detonations in the winter of 1962 from the Nevada site, and commenced an extensive series from the Pacific site during April, May and June of 1962. This series was closed with the famous Starfish detonation. Although the detailed transport, diffusion, and residence of debris at very high altitudes is not completely understood, it seems possible a detectable amount might be found in the stratosphere over Minneapolis on June 10, 1962. Since the Cs^{137} line was measured in all positions, the source must extend to well above 130,000 feet. The range of the protons permits measurements when pointing down to about 70,000 feet, depending on the activity level.

The counting rate of the Cs^{137} line was about 0.14 ± 0.03 counts/sec. This means the source strength was 0.008 ± 0.002 disintegrations/gm-sec or $2.2 \pm 0.5 \times 10^{-13}$ curies/gm. at 100,000 feet. This may be compared with measurements reported by Gustafson, et al (1965) of 4.7×10^{-10} Curies/gm at 68,000 feet over Thule, Greenland on 14 September 1962. A measurement was made by Anderson (1965) of 5×10^{-13} curies/gm at 61,000 over Flin Flon, Canada on 2 October 1962.

SUMMARY

This experiment has resulted in new upper limits on the solar flux at the earth over the range of 160-800 kev. An upper limit of about 0.05 photons/cm^2-sec within this range was measured. The quiet time flux leaking from the solar surface must then be less than about 200 photons/cm^2-sec over this energy range. This puts a limit on such processes as nuclear reactions in the solar chromosphere and photosphere, electrons trapped in weak solar fields and precipitating into the solar surface, and slow or continuous acceleration in chromosphereic fields.

Information was also obtained on the application of active anti-coincidence shields as a collimating device for γ-ray astronomy. This instrumental technique is very effective in reducing γ-ray background in a radiation environment where the source strength is large. In the instrument used in this measurement, most of the counts, at least near 300 kev, were due to production in the matter and atmosphere within the forward aperture of the instrument. This allows a search for γ-rays from a known point object to be accomplished at high sensitivity by subtracting the results of an independent background observation. In this experiment, a statistically determined limit for solar γ-rays of about 5% of the total background rate was obtained.

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TABLE I

Summary of Rates and Upper Limit Fluxes

Energy Range (kev)	Toward Sun (Counts/Sec)	Away From Sun (Counts/Sec)	Differential Rate (Counts/Sec)	Upper Limit Flux ($Counts/cm^2$-sec-Mev)	Upper Limit Flux ($Photons/cm^2$-sec-Mev)
163-325	1.901 ± .036	1.928 ± .041	-0.027 ± .056	0.058	0.166
325-488	0.961 ± .027	0.973 ± .030	-0.012 ± .042	0.048	0.171
488-651	0.704 ± .023	0.705 ± .026	0.001 ± .037	0.050	0.263
651-774	0.374 ± .015	0.366 ± .016	0.008 ± .020	0.043	0.307
> 774	1.223 ± .015	0.994 ± .015	0.23 ± 0.02	0.030 ± 0.002	$Counts/cm^2$-sec

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Figure Captions

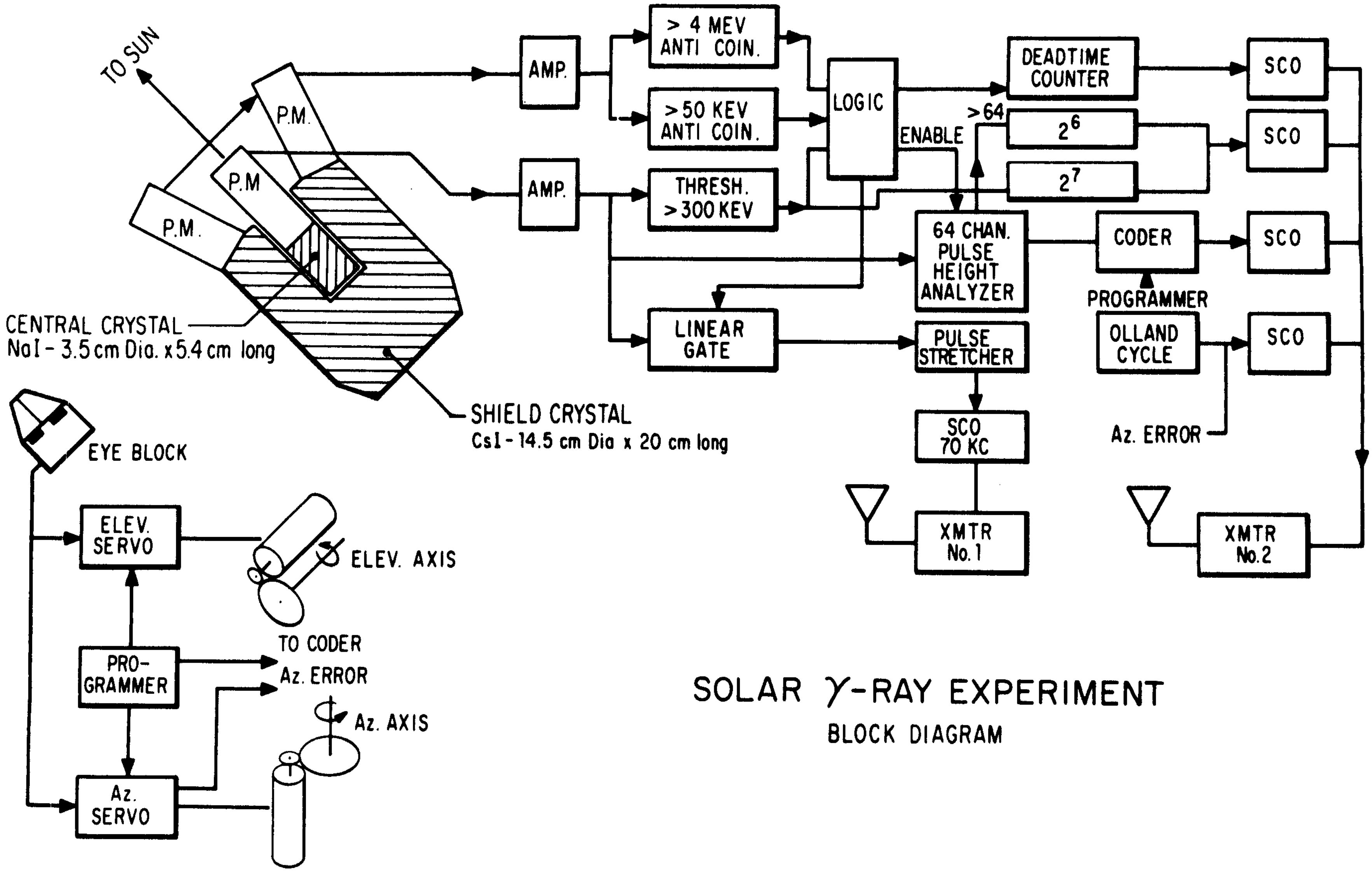
1. Detector and block diagram of the instrumentation used in a search for low-energy solar γ-rays. The detector had an area of 9.1 cm^2 and an acceptance cone of about 1 steradian. Two independent pulse-height data transmission systems were employed.
2. Measured angular response of the detector to Cs^{137} γ-rays. The response, particularly at wide angles, is dependent on photon energy.
3. The profile of the balloon flight. Upon reaching altitude, the detector went through a pointing sequence each hour to provide information required to correct for atmosphere γ-ray background. There is no obvious solar flux. The high rates of the digital analyzer occurred because of the partial loss of the anti-coincidence gate.
4. The deadtime due to cosmic-ray events in the shield as a function of atmospheric depth. This was independently measured, and is due to two effects, many small pulses with a short deadtime and large cosmic-ray events with a long deadtime.
5. The rates of various counting functions as a function of atmospheric depth. Most of the rates indicated a cosmic-ray type transition maximum, and an absorption length of 180 gm/cm^2 deep in the atmosphere. The depth independent rate of the central counter is apparently due to an undetermined background effect; the steep slope measure by the high range analyzer is due to γ-ray production in the CsI shield when the anti-coincidence was ineffective.

6. The spectrum, corrected for deatimes and channel widths. A small difference is noted due to zenith angle effects; the data to and away from the sun are averaged together. The line at 0.5 Mev, due to positron annihilation both in the air and in the CsI shield is clearly indicated.

7. The upper limit γ-ray spectrum from the quiet sun as observed at the earth. Observations in this experiment are compared with those from the OSO-1, the Ranger series, and recent rocket measurements at lower energy. The earlier observations in the Mev range are uncorrected for efficiency. Gamma-rays above about 10 kev must clearly have a non-thermal origin.

8. Comparison of upper limits on the Crab Nebula obtained by this experiment with upper limits and fluxes measured by Clark (1965) and NRL (Bowyer et al, 1964). Our upper limits are uncorrected for efficiency.

9. Spectra of atmospheric γ-rays as determined in this experiment, compared with a previous measurement at the same location. Since the main counters had nearly the same geometry, the difference at high energies must be due to background effects or leakage through the shield.



SOLAR γ-RAY EXPERIMENT

BLOCK DIAGRAM

Fig. 1

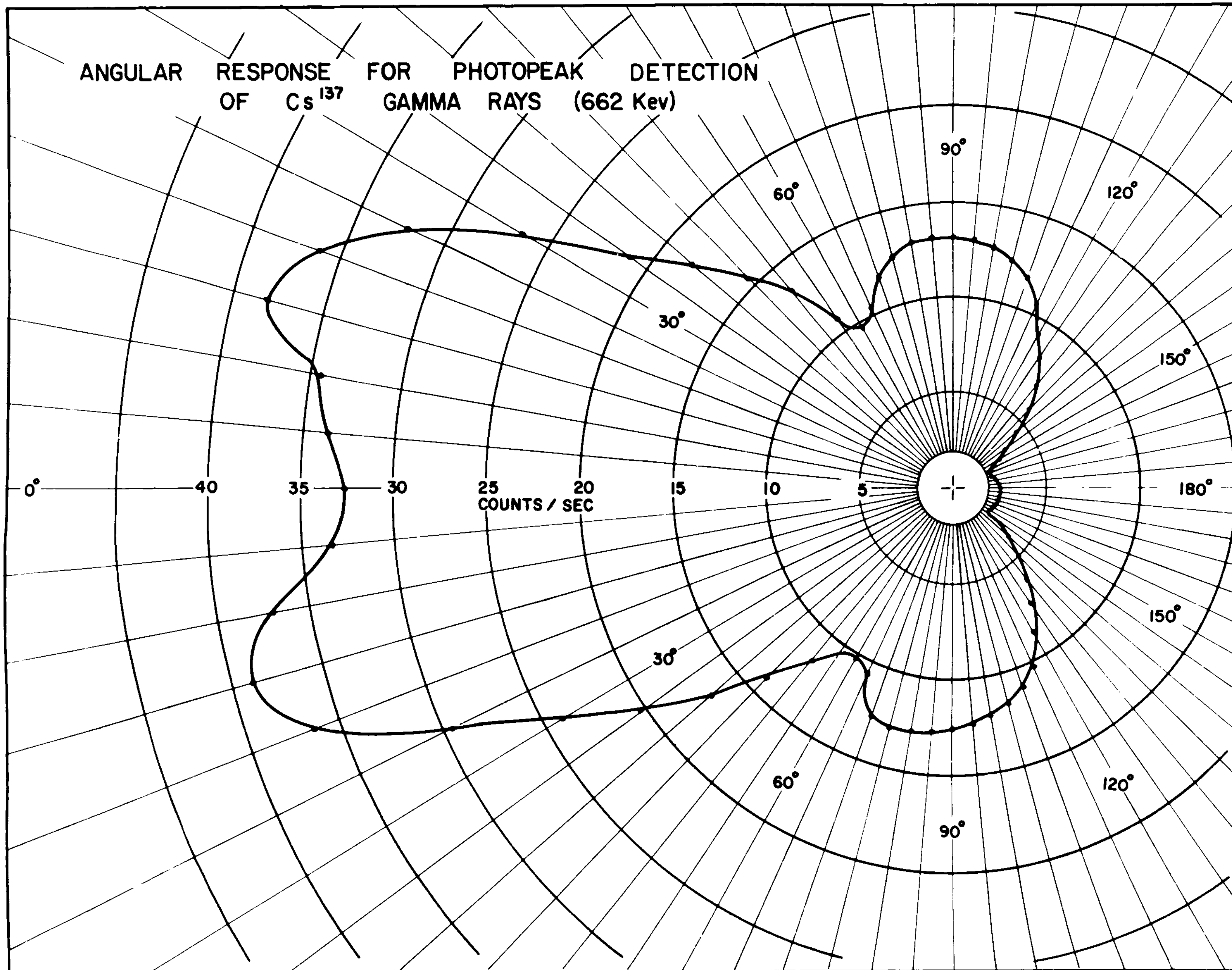

ANGULAR RESPONSE FOR PHOTOPEAK DETECTION
OF Cs 137 GAMMA RAYS (662 Kev)
0°
40
35
30
25
20
15
10
5
COUNTS / SEC
30°
60°
90°
120°
150°
180°

Fig. 2

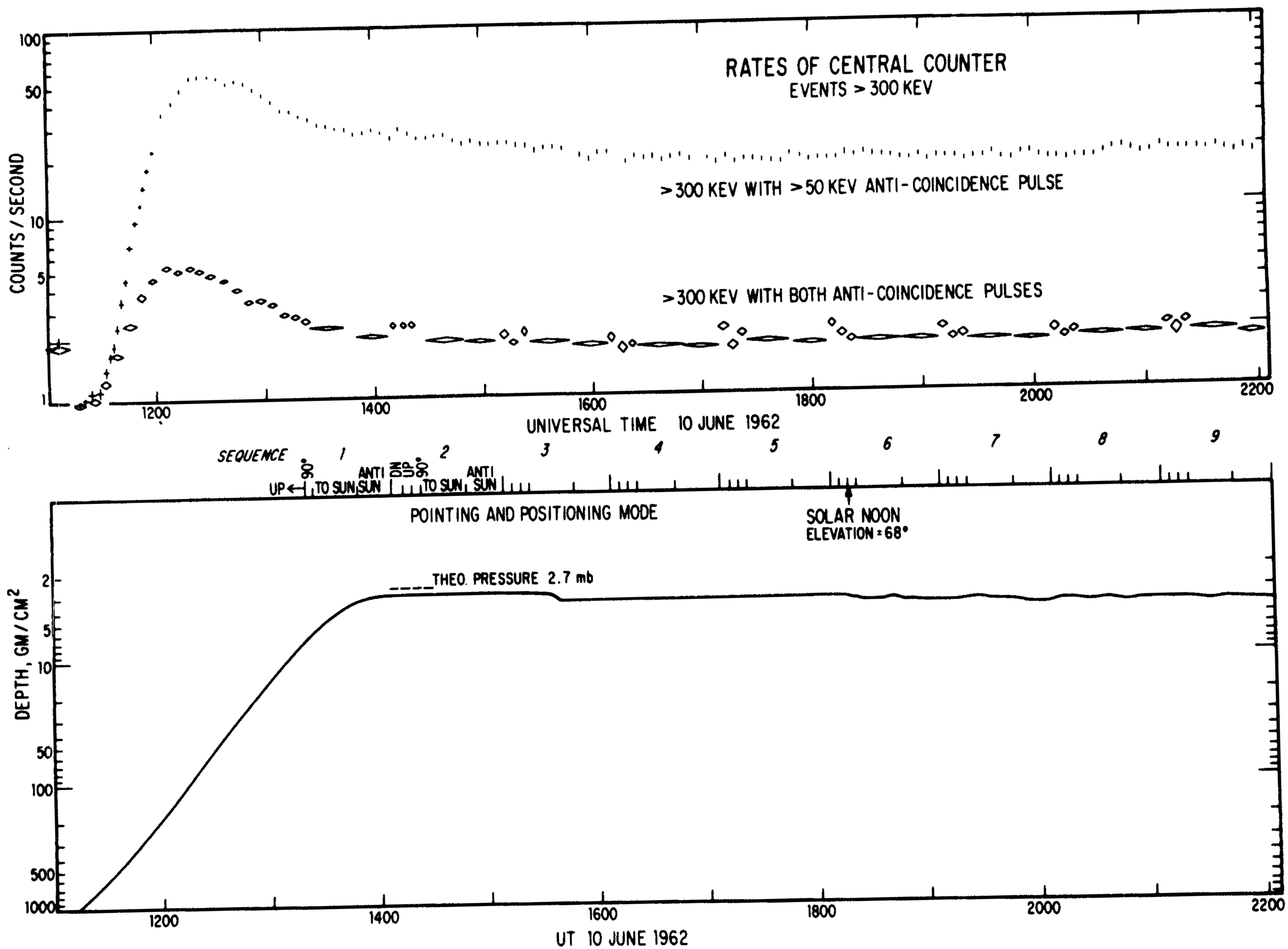
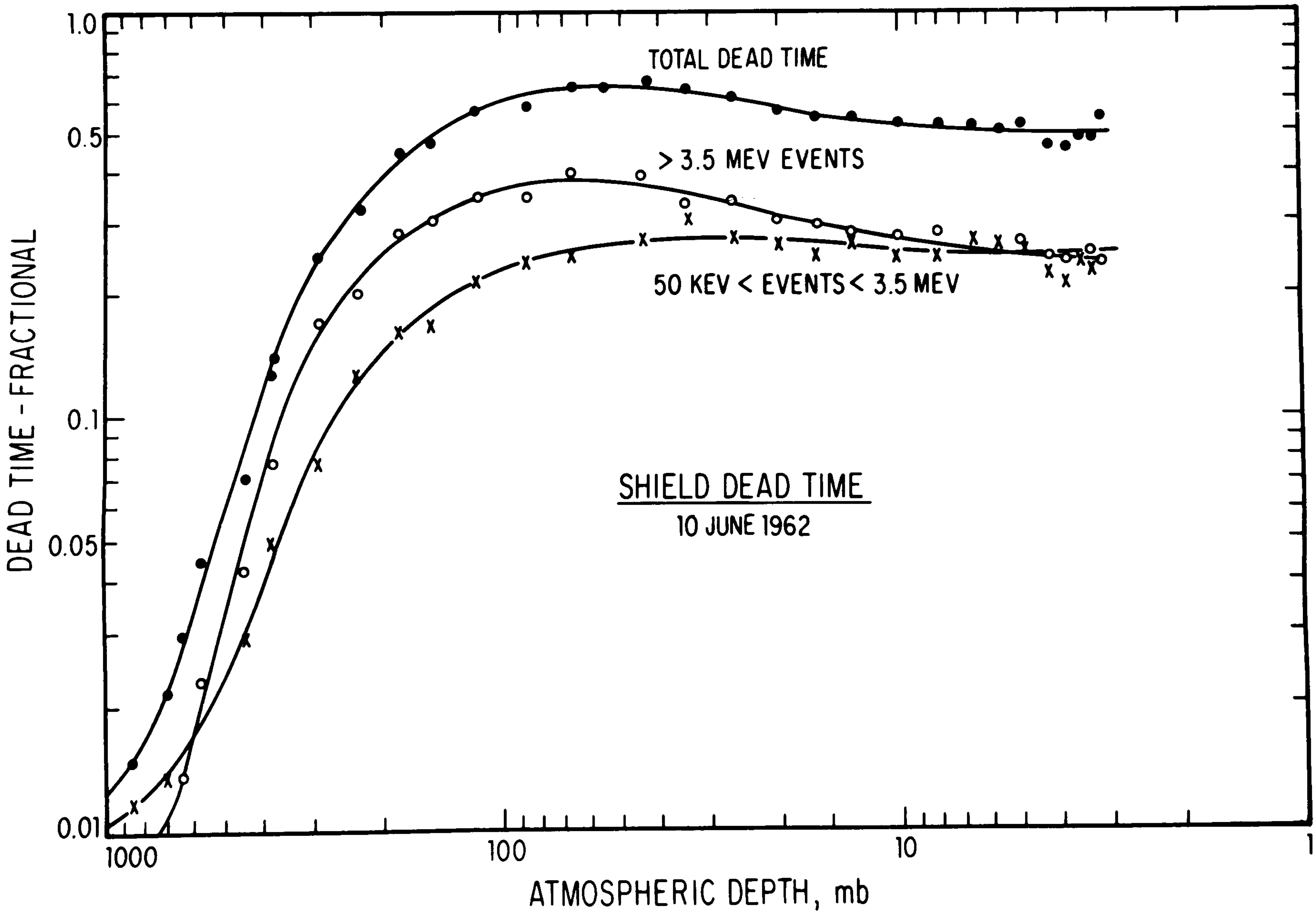

RATES OF CENTRAL COUNTER
EVENTS > 300 KEV
>300 KEV WITH >50 KEV ANTI-COINCIDENCE PULSE
>300 KEV WITH BOTH ANTI-COINCIDENCE PULSES
COUNTS / SECOND
UNIVERSAL TIME 10 JUNE 1962
SEQUENCE
UP
TO SUN
ANTI SUN
TO SUN
ANTI SUN
POINTING AND POSITIONING MODE
SOLAR NOON
ELEVATION = 68°
THEO. PRESSURE 2.7 mb
DEPTH, GM/CM²
UT 10 JUNE 1962

Fig. 3



TOTAL DEAD TIME
> 3.5 MEV EVENTS
50 KEV < EVENTS < 3.5 MEV
SHIELD DEAD TIME
10 JUNE 1962
DEAD TIME - FRACTIONAL
1.0
0.5
0.1
0.05
0.01
1000
100
10
1
ATMOSPHERIC DEPTH, mb

Fig. 4

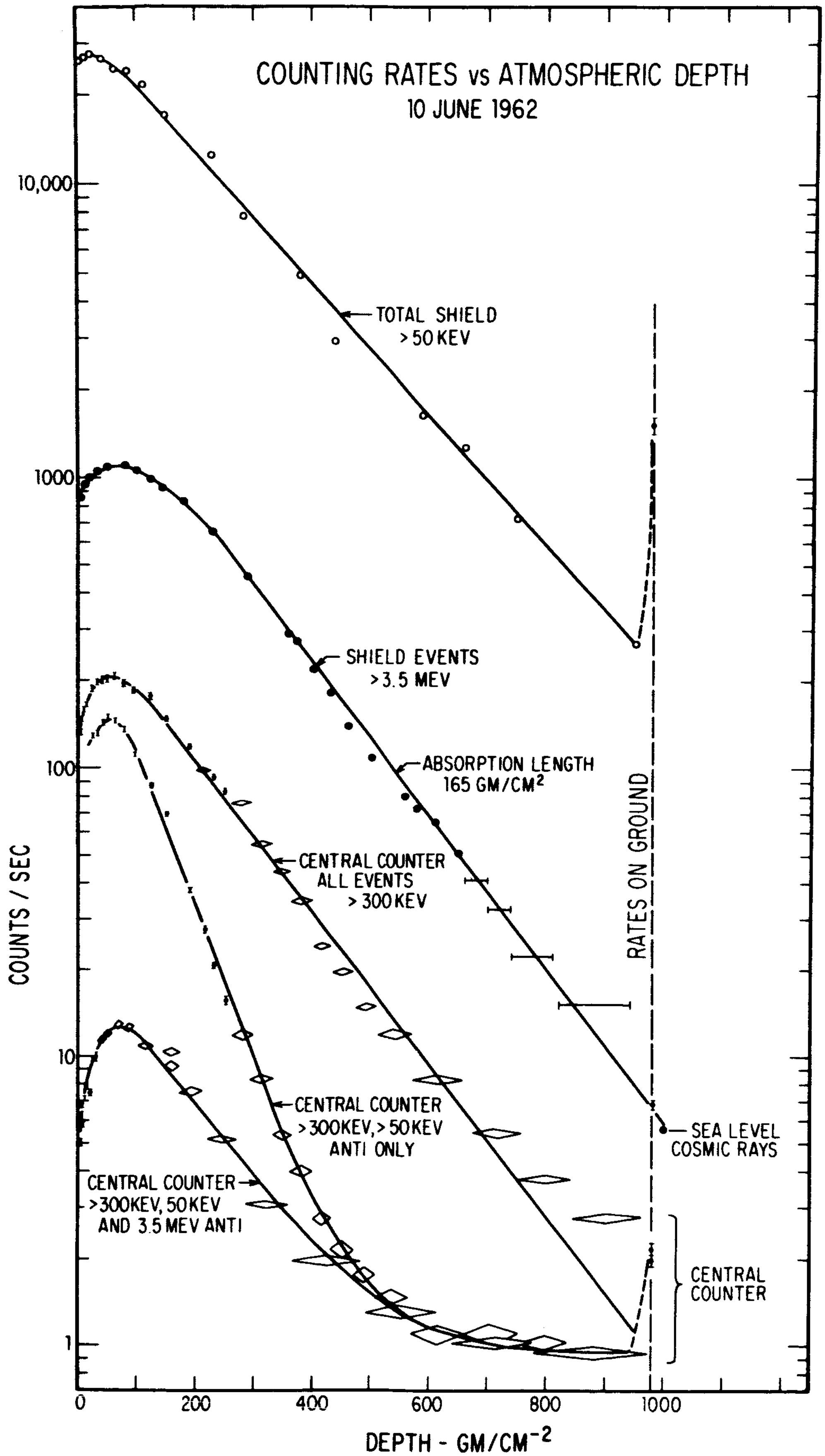
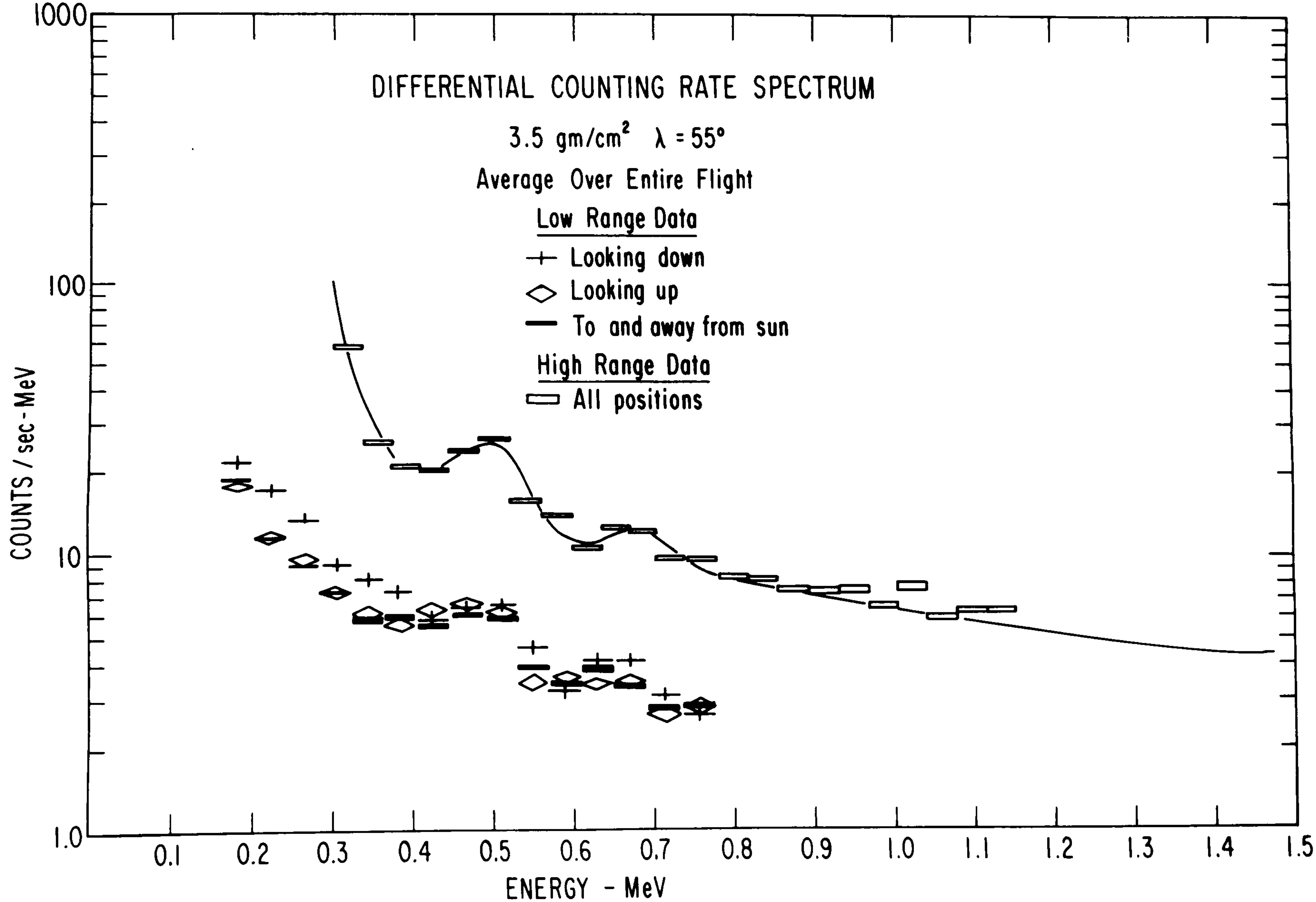
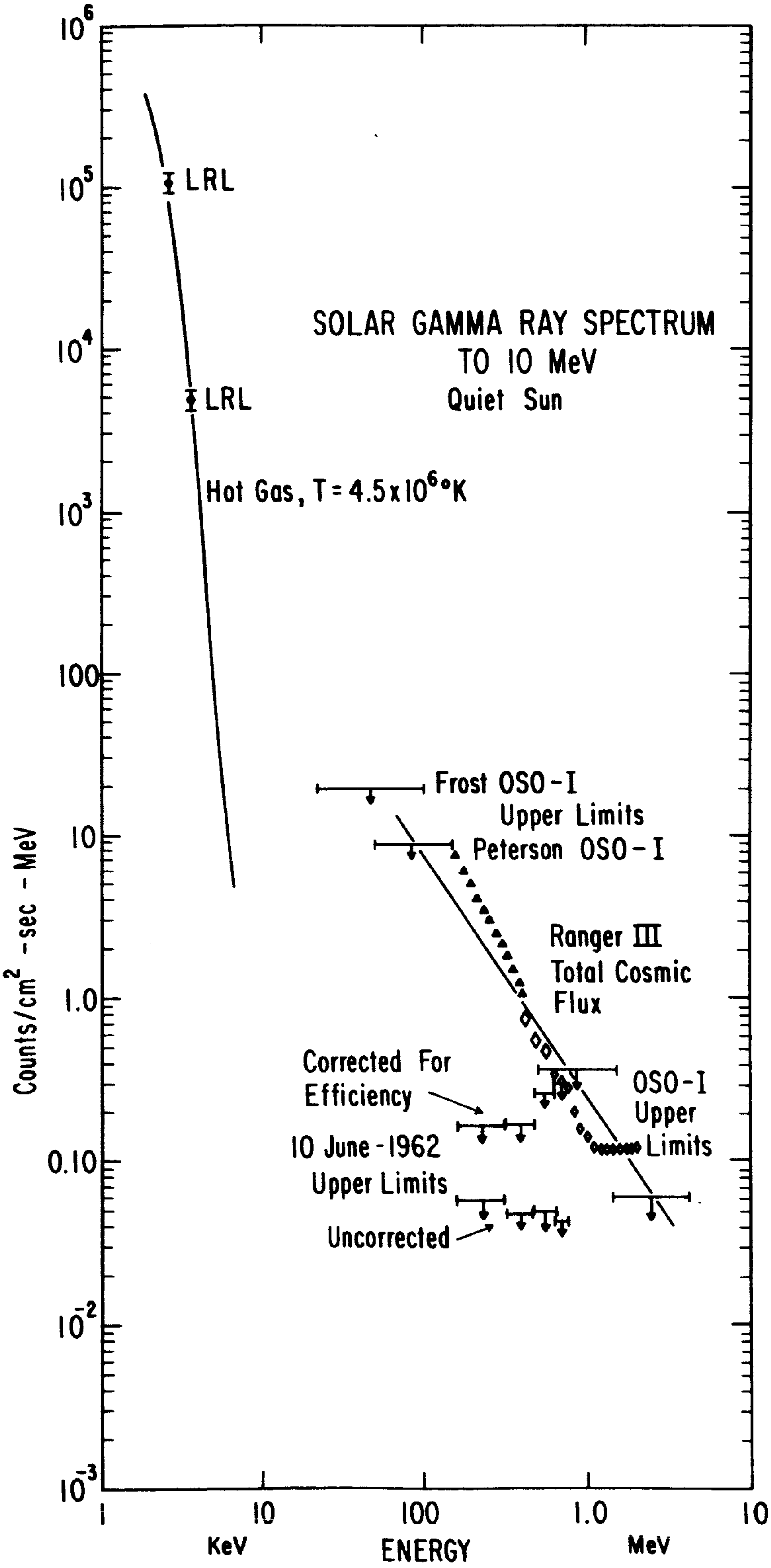

COUNTING RATES vs ATMOSPHERIC DEPTH
10 JUNE 1962
10,000
1000
100
10
1
COUNTS / SEC
0
200
400
600
800
1000
DEPTH - GM/CM^{-2}
TOTAL SHIELD
>50 KEV
SHIELD EVENTS
>3.5 MEV
ABSORPTION LENGTH
165 GM/CM^2
CENTRAL COUNTER
ALL EVENTS
>300 KEV
CENTRAL COUNTER
>300KEV, >50 KEV
ANTI ONLY
CENTRAL COUNTER
>300KEV, 50 KEV
AND 3.5 MEV ANTI
RATES ON GROUND
SEA LEVEL
COSMIC RAYS
CENTRAL
COUNTER

Fig. 5



DIFFERENTIAL COUNTING RATE SPECTRUM
3.5 gm/cm² λ = 55°
Average Over Entire Flight
Low Range Data
Looking down
Looking up
To and away from sun
High Range Data
All positions
1000
100
10
1.0
COUNTS / sec-MeV
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
ENERGY - MeV

Fig. 6



SOLAR GAMMA RAY SPECTRUM
TO 10 MeV
Quiet Sun
LRL
LRL
Hot Gas, T = 4.5 x 10⁶ °K
Frost OSO-I
Upper Limits
Peterson OSO-I
Ranger III
Total Cosmic
Flux
Corrected For
Efficiency
10 June-1962
Upper Limits
Uncorrected
OSO-I
Upper
Limits
Counts/cm² -sec -MeV
ENERGY
KeV
MeV
10⁶
10⁵
10⁴
10³
100
10
1.0
0.10
10⁻²
10⁻³
1
10
100
1.0
10

Fig. 7

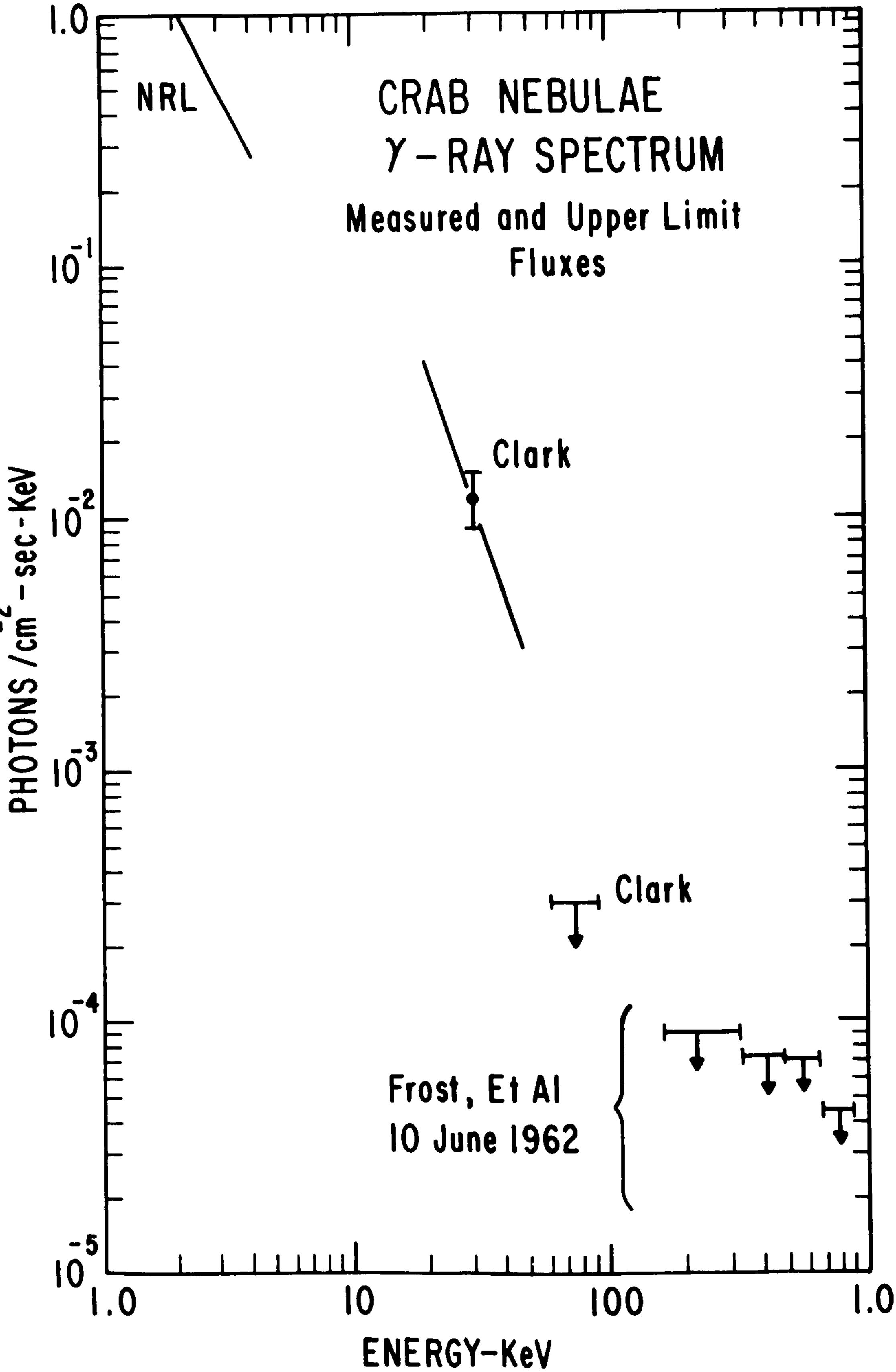
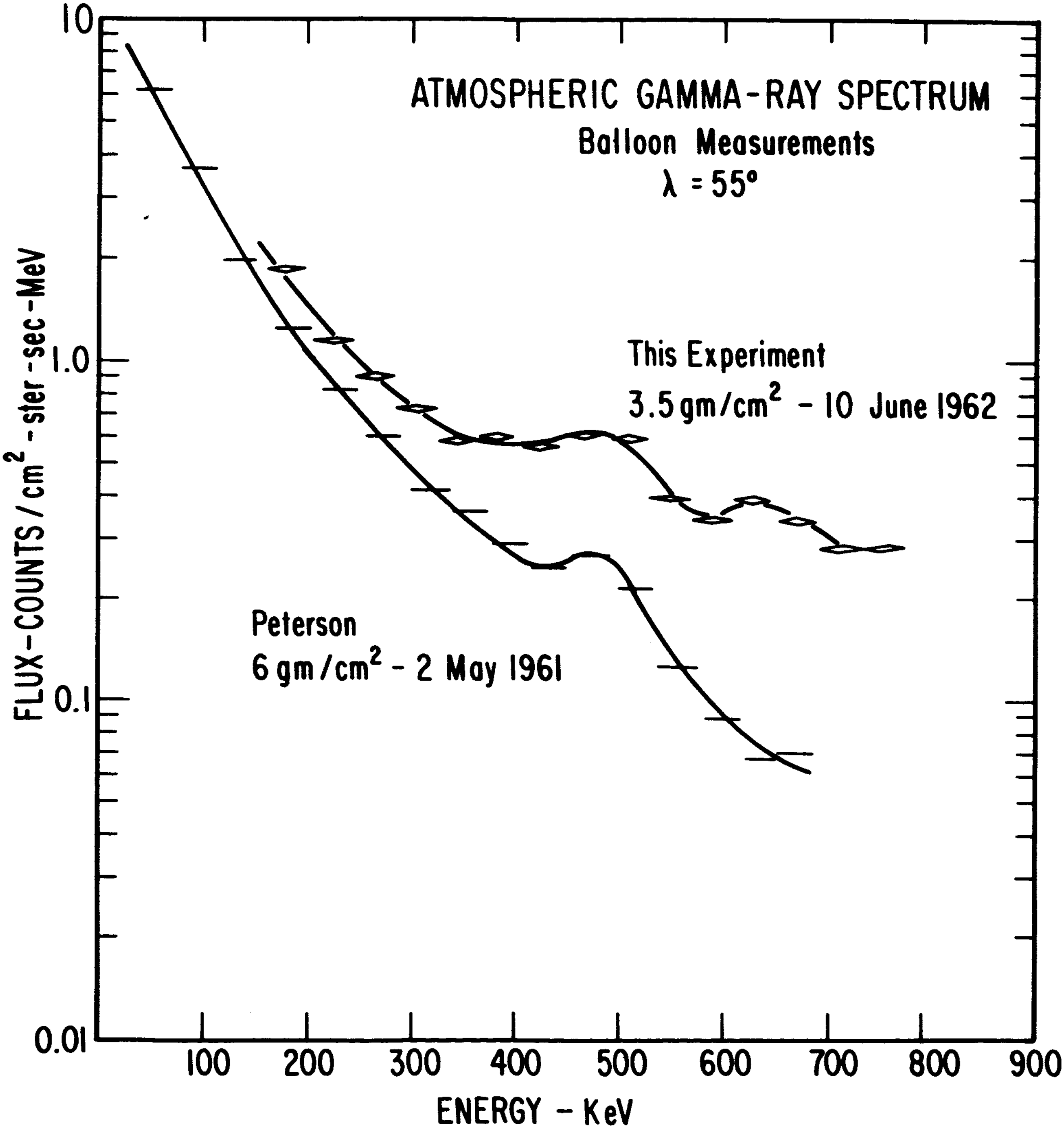

CRAB NEBULAE
γ-RAY SPECTRUM
Measured and Upper Limit
Fluxes
NRL
Clark
Clark
Frost, Et Al
10 June 1962
PHOTONS /cm^-2 -sec-KeV
ENERGY-KeV
1.0
10^-1
10^-2
10^-3
10^-4
10^-5
1.0
10
100
1.0

Fig. 8



ATMOSPHERIC GAMMA-RAY SPECTRUM
Balloon Measurements
λ = 55°
This Experiment
3.5 gm/cm2 - 10 June 1962
Peterson
6 gm/cm2 - 2 May 1961
FLUX-COUNTS/cm2-ster-sec-MeV
10
1.0
0.1
0.01
100
200
300
400
500
600
700
800
900
ENERGY - KeV

Fig. 9